# Simulations for mechanical design of nozzle for extrude of windowless solid hydrogen cryogenic target.

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# SIMULATIONS FOR MECHANICAL DESIGN OF NOZZLE FOR EXTRUDE OF WINDOWLESS SOLID HYDROGEN CRYOGENIC TARGET

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*Abstract*

The hydrogen ($H_2$ and $D_2$) target is a determining element of unstable nucleus spectroscopy. This target is proposed for studies of exotic nuclei beams of several MeV/nucleon in SPIRAL and SPIRAL2 Projects. Within the project of CHyMENE (Cible d'Hydrogène Mince pour l'Etude des Noyaux Exotiques), the development of hydrogene target is supported by ANR(Agence National de la Recherche) which federates differents French research institutes such as CNRS and CEA [1, 2]. The goal of CHyMENE's project is the production of a hydrogen film with a thickness of fifty micron as target for radioactive nuclei beam. It's an innovative design. IPN Orsay is involved in the conception and simulations of a nozzle which can deliver a solid ribbon of fifty microns thickness; it is a very challenging program since the knowledge about hydrogen solid at 12 K is rare, especially in terms of experimental characterizations. The important work consists at first to propose models of simulations in order to study mechanical behaviours of hydrogen solid at cryogenic temperature under pressure and optimize the geometry parameters as well as rheology properties of nozzle. The non linear mechanical modelling concerning not only materials but also contact behaviours is presented. The first simulations results are summarized.

## INTRODUCTION

A windowless solid hydrogen target has been successfully developed at CEA Saclay. The advantage of windowless target is to avoid the carbon contamination of $H_2$. The solid hydrogen target takes the form of a very thin film whose thickness can be reduced presently to $100\mu m$. Even if it's already challenging to reach this thickness, the physicist are especting a film of $50\mu m$ thickness, but the minimum thickness limite is unknown. For this, an initiative is to create numerical modeling in order to make simulations of hydrogen solid film's forming. We are in charge to optimize the nozzle which can be modeled as a solid wall made of copper. The solid hydrogen is first entirely filled inside the copper wall, then pushed out of nozzle by sequential deformations.

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## GEOMETRIC MODELING OF SOLID HYDROGEN AND NOZZLE

The extruder design has been elaborated in order to deliver a very thin film. The rough sketch of preliminary design is shown in Fig. 1. The first stage is made of a special extruder developed by the laboratory of Pelin in Russia. This extruder pushes the hydrogen mass to the nozzle. We

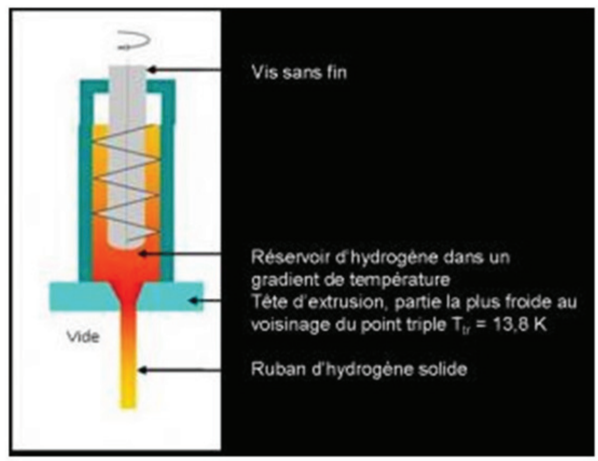


Figure 1: Extruder sketch.

have proposed different models of solid hydrogen in order to simulate the procedure of hydrogen film's formation as a consequence of the compression of solid hydrogen through the nozzle.

At first, we have proposed the nozzle concept (Fig. 2). The finite element method simulations are made in this concept with the numerical code Cast3m [3]. A 3D geometry modeling is tried (Fig. 4). But it's very time consuming, especially if the dimension of the outlet is very narrow (between $50\mu m$ to $100\mu m$) as compared to global dimension (several centimeters). The preference is a 2D modeling with quite fine mesh as shown in Fig. 5.

## PHYSICAL BEHAVIOURS OF SOLID HYDROGEN

Few documents exist concerning solid hydrogen's properties at low temperature. From Nasa experimentations data [4], we have learn some variations of the mechanical properties of solid hydrogen at low temperature: $\rho = 0.0875 g/cm^3$, $E = 5MPa$, where $\rho$ is the volumic density and $E$ is the Young modulus.




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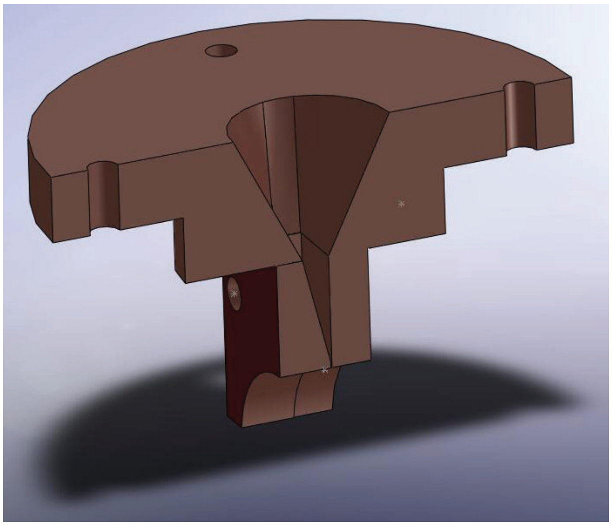

Figure 2: Nozzle design.

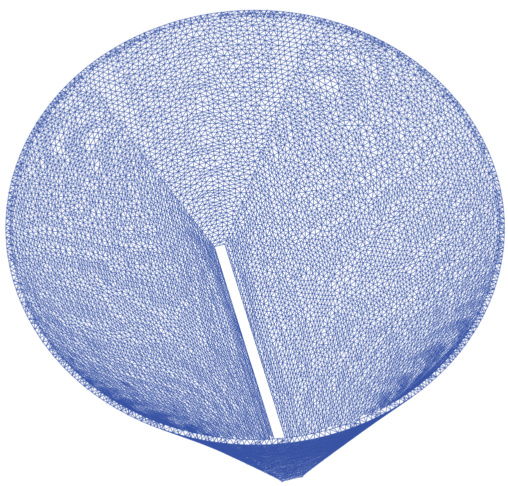

Figure 3: Nozzle 3D modeling.

The first attempt consists to assign a theorical physical law to solid hydrogen at low temperature. We have used a Bingham-type behavior Norton law.

In fact, the more simple mechanical model is elastic solid for which the mechanical behavior of solid is $\sigma = E\epsilon$, where the stress $\sigma$ is proportional to deformation $\epsilon$ with Young modulus $E$ as ratio of proportionality. The Norton law is a viscoplastic model of solid for which the deformation law is

$$\dot{\epsilon} = a * \sigma^b * t^c$$

where a, b, c are the empiric constants and the implicit parameters are Young modulus, Poison ratio and $\sigma_{max}$ which is egual to $E \times 1.10^{-3}$ by default.

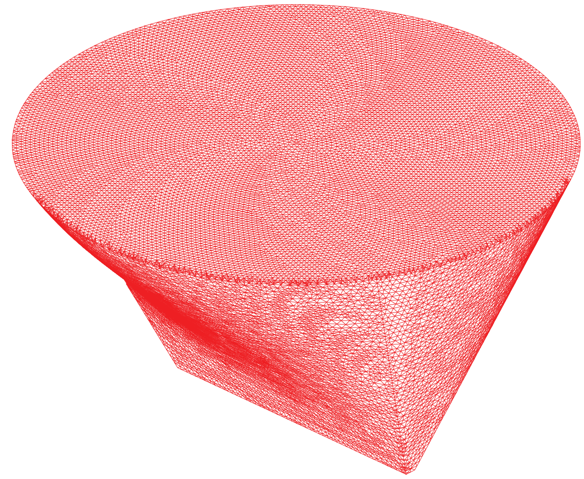

Figure 4: Solid hydrogen 3D modeling.

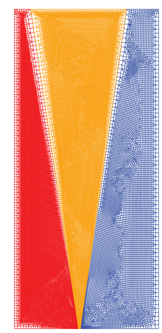

Figure 5: 2D modeling.

## CONTACT BETWEEN SOLID HYDROGEN AND NOZZLE

The junctions between solid hydrogen and nozzle wall is modelized by the friction laws. Considering two surfaces face to face between solid hydrogen and nozzle, two states are possible: first below a given threshold, depending on friction ratio and modulus of the force tangential component, there is no movement between two solids; second, above the threshold, there is movement between two solids.

By using Cast3m code, We have Coulomb law for friction desciption.

the unilateral contact law is [5]:

$$(\vec{u1} - \vec{u2}).\vec{n} \geq 0$$

Where $\vec{u1}$ and $\vec{u2}$ are the vectors displacements from two sides of contact. And the Coulomb law for friction is:
if

$$|F_t| \leq \mu |F_n|$$

then,

$$du/dt = 0$$

there is adhesion and
if

$$|F_t| = \mu |F_n|$$

then

$$du/dt = \lambda F_t$$

there is sliding.

In terms of finite element simulation, it consists to introduce the boundary conditions which modelize contact law with this appropriate friction law.

## SIMULATIONS RESULTS

The simulations have been performed gradually. Before archiving the simulations on the realist geometry which imposes $50\mu m$ for the nozzle slit dimension, a simple model has been used in order to simulate the friction phenomena. Figure 6 shows the case where the friction force prevent the solid hydrogen (green color) to glide along the extractor. On the other hand, if the force of pressure is sufficient, the hydrogen can push out of extractor as one goes along (Fig. 7).

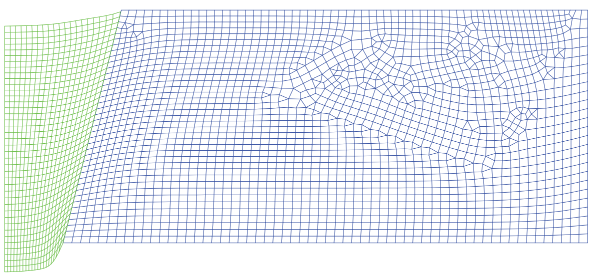

Figure 6: Axi symetric modeling: no gliding of $H_2$ (green) along nozzle (blue.)

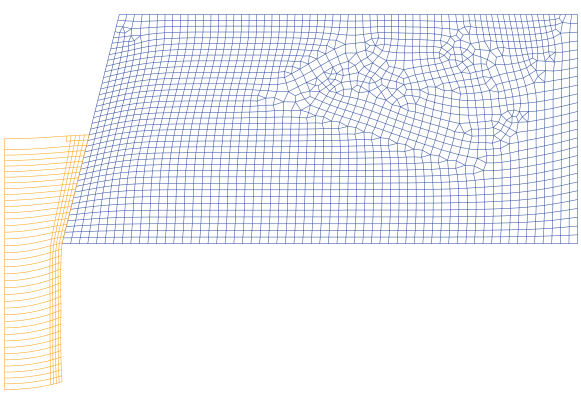

Figure 7: Axi symetric modeling: hydrogen solid (orange) gliding along wall of nozzle (blue).

On the second stage, more complex geometrical modeling has been performed. In a no axis symetry configuration, considering the case that the extractor is made of two welding objets. The plane deformations modeling, Fig. 8, includes two surfaces of friction. The influence of each surface can be taken into count. The simulations become more time consuming, depending on the exit slit's dimension, pression, and friction ratio. As an example, Fig. 8 illustrats solid hydrogen extraction through nozzle. The exit slit dimension is $100\mu m$ whereas the entrance dimension is $6mm$, the height is $20mm$.

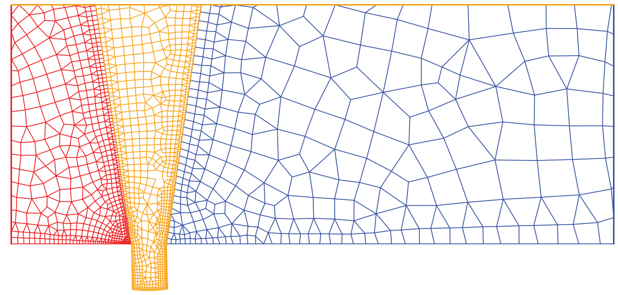

Figure 8: Zoom shot: $100\mu m$ hydrogen solid (orange) gliding along two wall of nozzle (red and blue).

## CONCLUSION AND PERSPECTIVES

Mechanical simulations have been performed on solid hydrogen extraction through a nozzle which can deliver $50\mu m$ to $100\mu m$ thick hydrogen target without window. The modeling is based on major deformations of hydrogen as a Bingham type viscoplastic materal which is in contact with nozzle according to Coulomb's law. The first numerical experimentations show that the extraction through a no axis symetric nozzle is more difficult than an axis symetric nozzle. The difficulty of extraction increases sensiblly as the thickness of the extracted film decreases. The improvement of the numerical experimentations is going on, more quantitative numerical characterisations are in progress. Some measurements of roughness are expected to anticipate of nozzle fabrication.

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